Indian J. Phys. **73B** (2), 331-335 (1999)

IJP
— an international journal

Some aspects of experimental high energy nuclear collisions : an overview and an interpretation

S Bhattacharyya and A C Das Ghosh
Physics and Applied Mathematics Unit, Indian Statistical Institute, Calcutta-700 035, India

Abstract The very topical and up-to-date data on some specific aspects in the laboratory-based nuclear collisions at very high energies, would be jotted here down in some detail, with emphasis on and angularity in some theoretical ideas. The importance and implications of these data *vis-a-vis* the theoretical predictions of the models would also be highlighted against the appropriate contextual background

Keywords . Quark-gluon plasma, nuclear collisions, strangeness enhancement

PACS No. 25 75.DW

1. Introduction

The questions of production of minijets, baryons and antibaryons (thus of antimatter) and of strangeness enhancement are very topical and exciting issues in the high energy nuclear collisions from both theoretical considerations and experimental points of view. The measured and the model-based predicted ratios of antibaryon-to-baryon constitute the central theme of interest as they provide information [1] on the space time evolution of the high density state formed in ultrahigh energy collisions. Besides, increased production of antinuclei in such collisions was one of the crucial predictions of the quark-gluon plasma (QGP) hypothesis [2]. This is because the dense plasma contains many more antipartons than are normally found in the parton-antiparton sea of proton-proton interactions. An enhanced production of antinucleii would also provide support to the picture of baryons as topological solitons in a chiral condensate as has been postulated from some other hypothetical (theoretical) considerations [3]. The issues are also of interest even from astroparticle and cosmological points of view [4-7].

With respect to the above-stated theoretical background, we would collect here some very up-to-date salient features of the experimental data obtainable from the laboratory-based high energy nuclear collisions. Furthermore, we would also try to decipher the concrete messages and signals on the existing models in the light of the available data.

2. Highlights on the salient experimental features

The followings are the key points from various high energy experiments involving hadrons (nucleons) and nucleii or any pair of nucleus-nucleus collisions.

(i) The NA 35 data on strange production at 200 A GeV/c demand that the strangeness suppression factor λ be 0.2 for proton-proton and proton-nucleus collisions whereas for nucleus-nucleus collisions the suppression factor is roughly 0.3 [8].

(ii) The negative multiplicity dependence of λ particle in S + Pb reactions at 200 A GeV/c and Pb + Pb reaction at 158 A GeV/c show slight discrepancies between measurements and model based (LUCIAE-based) predictions.

(iii) The ratio of strange antibaryon π to the non-strange antibaryon $\bar{p}$ in central AA collision at 200 GeV per nucleon is larger than one and therefore significantly larger than the ratio in NN interactions.

(iv) The $\bar{d}/\bar{p}$ ratio at mid-rapidity in Pb–Pb collisions was measured to be 4.2×10^{-4}.

(v) The anti-lambda to antiproton ratio is ~ 0.37 for nucleus involved collisions.

(vi) Some concrete values of strange antibaryon to baryon ratio in Pb–Pb collisions are obtained from the experimental report of Anderson *et al* [9] and of Sorge [10].

(vii) There was an observation of one antihelium – 3 nucleus in Pb–Pb [3] collisions at 158 GeV/c per nucleon.

3. The models for secondary light nucleii and other particle production

(A) For nucleus-nucleus collisions :

The coalescence model provides the necessary tool to make an attempt at analysing the production of secondary very-light-to-light nucleus production from the collisions of the heavies at very high energies. According to this model [11], the production of nucleii (antinucleii) with a mass number A scales as a-th power of the production of nucleons (antinucleons).

$$E_A \frac{d^3\sigma_A}{dP_A^3} = \alpha_A \delta_0 (1-A) \left(E_p \frac{d^3\sigma_p}{dP_p^3} \right) \tag{2a}$$

$$\text{with } P_A = A.P_p , \tag{2b}$$

where the symbols have their usual contextual significance as given in Ref. [11]

The model also predicts that the coalescence scaling factor should be the same for a nucleus and an antinucleus. The following values of the scaling factor for deuteron and tritium productions in the lead + lead (Pb + Pb) collision was obtained :

$$\alpha_2 = (1.5 \pm 0.4) \times 10^{-3} \text{ GeV}^2 / c^3,$$

$$\alpha_3 = (8.0 \pm 8.0) \times 10^{-5} (\text{GeV}^2 / c^3)^2.$$

At the relatively lower energies the scaling factor for deuteron was obtained to be

$$\alpha_2 = 1.5 \times 10^{-2} \ \text{GeV}^2/\text{c}^3 .$$

The change in values of the scaling factor, α_2 at two different ranges of energy has a bearing on the source size of the particles (nuclei) or antiparticles (antinuclei). The coalescence model assumes [11] that the highly excited region formed in the collision decays *via* particle emission. The momentum distribution of the particles within that region as well as the emitted composite particles are described by density matrices [1]. The production yields of composite particles with respect to the nucleon production yields are related to the internal wave production parameter, v_A of the composite particle A and the source size parameter, v

$$E_A \frac{d^3\sigma_A}{dP_A^3} \Big/ E_p \frac{d^3\sigma_p}{dP_p^3} \alpha \left(\frac{\hbar}{m_N C^2}\right)^{A-1} \left(4\pi \frac{v_A v}{v_A + v}\right)^{3/2(A-1)}$$

where the rms source size radius is $R = \sqrt{3/(2v)}$. In this analysis, the wave function parameters

$$v_d = 0.20 \text{ fm}^{-2} , \ v_t = v_{^3He} = 0.36 \text{ fm}^{-2}$$

had been used from Sato and Yazaki [11]. The derived source sizes for nuclei and antinuclei are listed from Ambrosini *et al* [1] in the following Table 1.

Table 1. Values of the source size parameters and the coalescence model A = Mass number, P_o = energy of the participating nucleus and R = source size radius

Collision type (energy)	Particle or antiparticle	A	P_o (MeV)	R (fm) rms (Approx)
Pb + Pb	d	2	49.1 ± 4.2	7 15
(158 GeV/c per nucleon)	$\bar{d}$	2	51.4 ± 5.2	6.79
	^{3}He	3	64.7 ± 5 6–10 3	6.70
	^{3}-He	3	113 + 14–113	3 44
	t	3	63.0 + 69–17.9	6 90
S + W	d	2	100 ± 12	2.55
(200 GeV/c per nucleon)				

(B) For nucleon-nucleon collisions :

The parametrisation of differential cross section $PP \rightarrow CX$ is of utmost use and importance for final calculations. The differential cross section $I\,(PP \rightarrow CX)$ is factorised here as follows.

$$I(PP \rightarrow CX) f = f_c\,(y)\, g\,(P_T)$$

with $f_c(y) = \beta c\,(1 - y)^{\beta c}$

The values of βc are given in Table 2 [12]

Table 2. Model parameters for beta-values

Particle-type	Beta-Value
Lambda	0.581
Sigma	1.230
Cascade''	2.570
Cascade	3.510
Omega	4.880
Antibaryons (all)	7.850

The numerical values of $(\text{Beta})_c$ do depend on the mass of the particle-type ; for baryons while the data are compatible with a unique value (7.850) for all antibaryons.

Next, we propose a behavioural pattern for the second part in the above-mentioned factorisation formula, *i.e.*, for $g(p_T)$ [13]. The form of $g(p_T)$ can be expressed as an exponential function with a coefficient, $\exp(-b\,p_T)$ with b values to be represented by the following form, $b = 2/\langle p_T \rangle$, where $\langle p_T \rangle$ is the average transverse momentum of the particle and the values of b are :

$$b_{\pi^+} = 6.5,\; b_{\pi^-} = 7.0,\; b_{K^+} = 5.0 = b_{K^-}$$

$$b_p = b_{\bar{p}} = 4.0 \text{ and } b_d = b_{\bar{d}} = 2.7 \text{ (all in GeV/c)}$$

4. Model-based calculated results

Table 3. Comparison of theoretical and experimental values on single particles

Particle and antiparticle	Rapidity (y)	Experimental cross section $\frac{\text{barn}}{\text{GeV}^2}c^3$		Model-based calculations for minimum bias events $\frac{\text{barn}}{\text{GeV}^2}c^3$	
K^+, K^-	3.01	39.90,	13.20	35.48,	11.50
	3.70	32.50,	20.50	33.68,	17.90
	4.40	22.90,	15.80	30.88,	15.75
	5.09	21.40,	7.30	24.75,	10.4
p and $\bar{p}$	2.38	21.14,	2.08	18.80,	2.78
	3.06	24.52,	2.01	26.65,	2.70
	3.75	30.64,	2.00	27.15,	1.80
	4.45	45.60,	0.578	40.40,	0.38
	5.35	– ,	7.9×10^{-4}	41.25,	5×10^{-4}
d and $\bar{d}$	1.71	0.182,	41.3×10^{-4}	---,	$< 10^{-5}$
	2.38	9.77×10^{-2}	7.3×10^{-4}	---,	$< 10^{-5}$
	3.06	8.91×10^{-2}	8.0×10^{-4}	---,	$< 10^{-5}$
	3.75	0.1663,	3.03×10^{-4}	---,	$< 10^{-5}$
	4.67	0.633,	29.00×10^{-6}	---,	$< 10^{-5}$
	5.36	5.30,	393×10^{-6}	---,	$< 10^{-5}$
^3He and $^3\overline{\text{He}}$	3.35	1.84×10^{-4},	4.6×10^{-6}	---,	4×10^{-4}

Table 4. Comparison of theoretical estimates with experimental measurements for some strange baryon to baryon (Antibaryon) ratios. [9]

Ratio	Corrected experimental value	Calculated model-based value
$\bar{\pi}/\pi$	0 14 ± 0.03	0.21
$\bar{\Theta}/\Theta^-$	0 27 ± 0 05	0.34
$\bar{\Omega}^+/\Omega^-$	0 42 ± 0 12	0 35
Θ^-/π	0 14 ± 0.02	0 22
$\bar{\Theta}^+/\bar{\pi}$	0.26 ± 0 05	0 36
Ω^-/Θ^-	0 19 ± 0 04	0 27
$\bar{\Omega}^+/\Theta^+$	0 30 ± 0.09	0 42
$\dfrac{\Omega^- + \bar{\Omega}^+}{\Theta^- + \bar{\Theta}^+}$	0.21 ± 0.03	0 19

5. Concluding Remarks

The models applied here might claim to have had so far only partial success in the sense that the few observations shortlisted here for analysis in the light of the theories on nucleus-nucleus and nucleon-nucleon collisions constitute only the tip of the iceberg. The vast sea of data on multiparticle production for several nucleus-nucleus collisions still remain unexplored by any model whatsoever, even for collisions at relatively lower energies [14].

What has to be emphasised upon is NOT the agreement of values of only the ratios ; rather the actual cross section and the multiplicities of the various particle-types are to be experimentally correctly measured and to be computed by model-based calculations for clarity and conviction. The reason for this statement is simply obvious.

References

[1] G Ambrosini *et al Phys. Lett.* **B417** 202 (1998)

[2] Frank Wilczek : a) *Nature* **391** 330 (1998) b) *Int J. Mod Phys.* **A13** 863 (1998)

[3] G Applequist *et al* : *Phys. Lett* **B376** 245 (1996)

[4] Gabriele Veneziano Preprint CERN-TH/98-43 (1998)

[5] Maurice Jacob *Int J Mod Phys* **A11** 4943 (1996)

[6] Samuel C C Ting *Int. J. Mod Phys* **A11** 3609 (1996)

[7] A Waheed and G Furlan *La Riv. Nuovo Cim.* **19** 5 (1996)

[8] Tai An and Sa Ben-Hao *Phys. Rev.* **C27** 261 (1998)

[9] E Anderson *et al Nucl Phys.* **A852c** (1998)

[10] H Sorge *Nucl. Phys.* **A630** 552c (1998)

[11] H Sato and K Yazaki *Phys Lett.* **B98** 153 (1981)

[12] Th. Kachelhoffer and W M Geist *Phys. Lett.* **B394** 225 (1997)

[13] S N Ganguli and B V Sreekantan *J. Phys.* **9** 331 (1976)

[14] M Tantawy, M el Mashad, N Y El Bakry *Indian J. Phys.* **72A** 73 (1998)